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and the “Contract Zone” in
Final Offer Arbitration**

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European University Institute
Badia Fiesolana
I – 50016 San Domenico (FI)
Italy

The "Divergent Beliefs" Hypothesis And The "Contract Zone" In Final Offer Arbitration

By Robbin Herring¹
European University Institute
Via dei Roccettini 9
I-50016 San Domenico di Fiesole
Florence, Italy
e-mail:Herring@datacomm.iue.it

Abstract

This paper presents a model of final offer arbitration which allows one to consider the consequences of the direct costs of arbitration on final offers, something that has been neglected in the literature. Another, and more important advantage of the model of this paper is that it fully characterises the set of equilibrium offers and describes a class of cases for which the set of equilibria can consist of both agreement and disagreement equilibria. This shows that the concepts of a 'positive' and 'negative' contract zones are not mutually exclusive, as is generally presumed in the literature. This insight has important consequences both for the debate of whether a positive contract zone is sufficient for agents to agree and for most empirical arguments based on this assumption.

Since the model is driven by divergent beliefs about the true beliefs of the arbitrator the question of when and whether agents have divergent beliefs is of some importance. This paper thus uses the opportunity to partially reevaluate the debate on the divergent expectations hypothesis (and the evidence supporting it) in the light of the model of this paper.

¹ I am extremely grateful to Jim Mirrlees and Robert Waldmann for lots of help with this paper.

1. Introduction

During the 60's and 70's a debate evolved in the US concerning the relative merits of compulsory arbitration and the ideal form it should take¹. This debate both was encouraged by and encouraged legislation on compulsory arbitration in many US states. The two arbitration schemes which received most attention were 'conventional arbitration' in which the arbitrator chooses any weighted average of the final offers and 'final offer arbitration' in which the arbitrator is constrained to choose one of the final offers.

Despite the significant costs of arbitration a large number of disputes have to be settled every year by way of arbitration (see for example the table in Ashenfelter and Currie [1990]). Most answers to this puzzle emphasise risk aversion. However, some authors also indicated that divergent beliefs about the preferences of an arbitrator may be of importance. Relatively few attempts to model and assess this idea formally have however been made². This paper proposes a model of final offer arbitration, driven by divergent beliefs, which leads to new insights concerning the divergent expectations hypothesis and concerning agreement and disagreement in arbitration models more generally.

The by now standard model of final offer arbitration is due to Farber [1980]. He assumes that the bargaining parties at some stage decide to call in an arbitrator. They then deliver sealed offers to the arbitrator who selects the offer closest to his or her ideal settlement. This ideal settlement is not known

¹ It seems that final offer arbitration schemes were already used long before the 60's -see Treble [1986]. For a review of final offer arbitration schemes see Metcalf and Milnor [1992].

² Farber and Katz [1979] seem to have been the first ones to propose this idea in the arbitration literature. The idea that divergent expectations may be important in bargaining was however already put forward by Hicks [1963] who stated that:

"The majority of strikes are doubtless the result of faulty negotiation. If there is considerable divergence in opinion between the employer and the union representative [about the strike outcome]... then the union may refuse to go below a certain level ... and the employer may refuse to concede it. ... Under such circumstances, a deadlock is inevitable, and a strike will ensue; but it arises from the divergence of estimates and from no other cause.... Adequate knowledge will always make a settlement possible."
(Quoted from Farber [1980], footnote 5)

to the agents. The expected payoffs of the arbitration stage then define a range of offers which, if positive, describes the '(positive) contract zone'- the range of offers which are preferable to calling in the arbitrator. A positive contract zone is generally interpreted as implying agreement (i.e. no arbitrated solution). A negative range is referred to as a 'negative contract zone' and is interpreted as implying disagreement. In the Farber model a contract zone can be negative because one of the bargaining parties is too risk-loving. Babcock and Olson [1992] contains a straight forward extension of Farber's earlier model in which they allow agents to have subjective priors (i.e. divergent beliefs) about the arbitrator's ideal settlement.

This paper develops a model of final offer arbitration which differs from the models of Farber [1980] and Babcock and Olson [1992]. Even though the model of this paper assumes the same sort of arbitrator as in the above models it differs from them in that the arbitrator is called in when the (final) offers at a certain stage are incompatible. The arbitrator then has to choose one of these (final) offers. Hence in this model agents are not expected to change their offers any more after entering the arbitration stage, that is, when going to arbitration the agents use exactly the same incompatible offers which forced them to go to arbitration.

This slightly different way of perceiving final offer arbitration has several important advantages. First, it allows one to consider the consequences of the direct costs of arbitration on the final offers. Although it is widely admitted that arbitration is expensive in terms of time, fees, etc., most³ authors only consider such indirect costs as risk aversion about an arbitrator's ideal settlement. Second, the model of this paper not only characterises the set of equilibrium⁴ offers which are preferable to letting the arbitrator decide (a

³ A notable exception is Bloom [1981] where a "negotiate or arbitrate" (page 236) decision is analysed. Farber [1980] contains an informal discussion of the likely effects of direct costs of arbitration.

⁴ An important caveat is in order here. The model is based on subjective beliefs about the arbitrator's preferences. Even though the authors in the literature refer to the resulting equilibrium as a Nash equilibrium, the underlying beliefs are arguably *not* Nash (at least as the terms is usually understood) since they are based on subjective beliefs. A detailed analysis and explanation of this issue is to be found in the Herring [1984] where it will be shown that the arbitration model of this paper can be couched in a two stage game and that the underlying beliefs then correspond to those of an extensive

positive contract zone) but also determines the set of equilibrium offers which imply that the arbitrator *should* decide (this situation is referred to in the literature as a 'negative' contract zone). Further, this model shows that for many beliefs about the arbitrator's true characteristics (i.e. the ideal settlement of the arbitrator) the set of equilibrium offers may contain offers which imply agreement *and* offers which imply disagreement (i.e. an arbitrated solution). This shows that the concepts of a 'positive' and 'negative' contract zone are not always mutually exclusive, as is generally believed in the arbitration literature (and as the name of a positive and negative contract zone suggests).

This insight has several important implications: it contributes to (and clarifies) a debate about whether the existence of a contract zone may be sufficient for agreement (see Bloom [1981] and Bloom and Cavanagh [1987]). Second, most tests of arbitration models are based on the presumption that disagreement can only occur if no positive contract zone exists (and that agreement occurs if a positive contract zone exists). In the context of this model this presumption can be wrong once agents are not assumed to have overly pessimistic expectations. Third, since models which claim to test for divergent expectations do so by assuming that divergent expectations can only exist once no positive contract zone exists, such tests may be completely misleading.

The model of this paper is primarily driven by differences in opinions or expectations about the arbitrator's preferences and by the direct costs of arbitration. Since the results of this model become strikingly different to those of the rest of the literature so long as expectations are not overly pessimistic, the question of whether and to what extent agents have divergent beliefs is of some importance. This paper will therefore use this opportunity to reevaluate the direct and indirect evidence on divergent expectations and the more theoretical claims that were made in this context.

The overall purpose of this paper is therefore as follows: to fully characterise the set of equilibrium offers and to describe situations in which the set of equilibria consists of both agreement and disagreement equilibria.

form subjective correlated equilibrium (see Forges [1986], Aumann [1974] and Fudenberg and Tirole [1991]). However, in order not to side-track attention from the main issues of this paper I will simply refer to the solution in this paper as an equilibrium.

These new insights are then used to reconsider a debate on whether the existence of a positive contract zone is sufficient for agents to agree and to assess what this implies for the empirical literature. Since the model is driven by divergent beliefs and since the results of this model become most striking (with respect to the remaining literature) once beliefs are divergent, the question of when and whether agents have divergent beliefs is of some importance. This paper will therefore attempt a reevaluation of the divergent expectations hypothesis and disagreement more generally.

Section 2 describes the model of final offer arbitration and characterises sets of solutions. In section 3 I will then go on to the debate of whether a positive contract zone is sufficient for agreement to occur. Section 4 then discusses the empirical and theoretical arguments that were made for and against the divergent expectations hypothesis. Section 5 concludes.

2. A Model of Final Offer Arbitration

Section 2.1 will describe the final offer arbitration model of this paper and section 2.2 will then give 'sufficient conditions' for several different equilibrium constellations to occur. The appendix contains a full characterisation of equilibrium.

2.1 A Model of Final Offer Arbitration

There are three players, the union (U), the firm (F) and the arbitrator. In the first stage U and F simultaneously announce their (final) offers. If these offers are incompatible then an arbitrator must choose one of the final offers. (Refer back to the introduction for an explanation of how this way of looking at arbitration differs from Farber [1980] and others). U and F choose their offers independently from the set $C = \{C_0, \dots, C_k\} = \{l: l=0, 1, 2, \dots, k\}$ for some finite⁵ integer k. Say that the players U and F divide profit π and an offer C_i by U or F is a suggestion that F gets C_i and U gets $\pi - C_i$, that is C_i is a

⁵ I assume a discrete strategy space which the arbitration literature does not do. This is not only a convenience assumption since a continuous strategy space in this model can lead to the non-existence of equilibrium due to discontinuities in the payoff function. Such non-existence problems do not arise with a discrete strategy space.

suggestion of what F (player 2) gets. I shall say that C_i^u and C_j^f are the suggestion by U and F to play C_i and C_j respectively.

The arbitrator has an ideal settlement C^a and it is assumed that it is an element of the strategy space C , that is $C^a \in C$. The arbitrator uses a minimum distance rule which is to choose the final offer closest to his or her ideal settlement C^a . The case in which the final offers are equally far away from the arbitrator's ideal settlement is not commented on in the arbitration literature. I will make an arbitrary assumption, (to be referred to as the 'equal distance assumption'), that in this case the arbitrator tosses a coin. The arbitration rule then is:

$$A(a, C_i^u, C_j^f) = p(C^a, C_i^u, C_j^f)C_i^u + (1-p(C^a, C_i^u, C_j^f))C_j^f$$

where

$$p(C^a, C_i^u, C_j^f) = \begin{cases} =1 & \text{if } |C_i^u - C^a| < |C_j^f - C^a| \\ =1/2 & \text{if } |C_i^u - C^a| = |C_j^f - C^a| \\ =0 & \text{if } |C_i^u - C^a| > |C_j^f - C^a| \end{cases}$$

This characterises the Arbitration stage. I assume, following Farber [1980] and the rest of the arbitration literature, that the bargaining agents do *not* know C^a . U and F believe that the arbitrator's ideal settlement is C^{au} and C^{af} respectively and for simplicity it will be assumed that $C^{au} \in C$ and $C^{af} \in C$. C^{au} and C^{af} need not be equal.

Payoffs in the final offer stage are defined as follows: If the offers of agents match, that is U offers F what F asked for, then U and F get the payoffs $(\pi - C_i^u, C_i^f)$ corresponding to the offers (C_i^u, C_i^f) respectively. If U offers F more than F demanded (that is U's and F's offers are (C_i^u, C_j^f) respectively where $i > j$) then they get payoffs⁶ $(\pi - C_j^f - 1/2(C_i^u - C_j^f); C_j^f + 1/2(C_i^u - C_j^f))$. If offers match or if U offers F more than F demanded then the arbitrator is not called in to settle the dispute. The variable δ denotes the discount rate of going to arbitration. A fixed cost would probably be more appropriate but would also require a little more notation and extra boundary conditions so that, for

⁶ One could also make the more general assumption that in this case U and F would respectively get $(\pi - C_j - \alpha(C_i - C_j); C_j + (1 - \alpha)(C_i - C_j))$ for any fixed $\alpha \in (1, 0)$

simplicity, I decided to use a discount rate to model the cost and the delay associated with arbitration⁷.

Consider strategy combinations (C_i^u, C_j^f) . The expected payoffs of the union then take the following form for any fixed C_j^f :

| Offers | Expected payoff to U | | |
|-----------------|------------------------------------|----|-------------------------------|
| $C_i^u > C_j^f$ | $\pi - C_j^f - 1/2(C_i^u - C_j^f)$ | | |
| $C_i^u = C_j^f$ | $\pi - C_j^f$ | | |
| $C_i^u < C_j^f$ | $\delta(\pi - C_i^u)$ | if | $1/2(C_i^u + C_j^f) > C^{au}$ |
| $C_i^u < C_j^f$ | $\delta(\pi - 1/2(C_i^u + C_j^f))$ | if | $1/2(C_i^u + C_j^f) = C^{au}$ |
| $C_i^u < C_j^f$ | $\delta(\pi - C_j^f)$ | if | $1/2(C_i^u + C_j^f) < C^{au}$ |

Equally, for any strategy C_i^u , the expected payoffs of the firm are defined as follows

| Offers | Expected payoff to F | | |
|-----------------|------------------------------|----|-------------------------------|
| $C_i^u > C_j^f$ | $C_j^f + 1/2(C_i^u - C_j^f)$ | | |
| $C_i^u = C_j^f$ | C_i^u | | |
| $C_i^u < C_j^f$ | δC_j^f | if | $1/2(C_i^u + C_j^f) < C^{af}$ |
| $C_i^u < C_j^f$ | $\delta 1/2(C_i^u + C_j^f)$ | if | $1/2(C_i^u + C_j^f) = C^{af}$ |
| $C_i^u < C_j^f$ | δC_i^u | if | $1/2(C_i^u + C_j^f) > C^{af}$ |

Now note that the union, for any C_j^f , always prefers $C_i^u = C_j^f$ to $C_i^u < C_j^f$, if $1/2(C_i^u + C_j^f) < C^{au}$, and $C_i^u = C_j^f$ to $C_i^u > C_j^f$. Equally F, for any C_i^u , prefers $C_i^u = C_j^f$ to $C_i^u < C_j^f$, if $1/2(C_i^u + C_j^f) > C^{af}$, and $C_i^u = C_j^f$ to $C_i^u > C_j^f$. The remaining cases then define the set of (pure strategy) 'equilibrium'⁸ (final) offers for any C^{au} and C^{af} .

2.2 Sufficient conditions

Solving for equilibrium final offers is not difficult but a full solution is intricate and somewhat cumbersome. For this reason the explicit equilibrium conditions are relegated to the appendix. Fortunately, a number of simple and

⁷ Bloom [1981] speaks of "the direct cost of arbitration, e.g., time costs and attorneys fees." (page 235). Time costs are well represented by way of a discount rate, attorneys fees less so.

⁸ Please remember the caveat made in a previous footnote on the usage of the term 'equilibrium' in this paper.

straight forward sufficient (but often not necessary) conditions for agreement and disagreement to be equilibrium action can be given. Below I will describe simple conditions in which agreement and disagreement equilibria exist. This will then make it possible to describe several situations in which the set of equilibria contains both equilibria which imply agreement and equilibria which imply disagreement. In property 1 a simple sufficient (but not at all necessary) condition for agreement to be an equilibrium action is that beliefs are compatible:

Property 1: Sufficient conditions for there to exist equilibrium (final) offers which imply agreement are that the expectations about the arbitrator's ideal settlement are compatible, that is $C^{au} \geq C^{af}$.

Proof: The proof of this property consists in constructing an equilibrium which implies agreement and which is based on these sufficient conditions. Consider offers $(C_i^{u*}, C_i^{f*}) = (C^{au}, C^{au})$ which imply payoffs $(\pi - C_i^{u*}, C_i^{f*})$. The only way U could increase its expected payoff is by decreasing C_i^u ; however since $C_i^{f*} = C^{au}$ this does not increase the U's expected payoff. Equally F cannot increase its expected payoff by increasing its offer since $(C_i^{u*} \geq C^{af})$. Hence $(C_i^{u*}, C_i^{f*}) = (C^{au}, C^{au})$ must be an equilibrium.

The question arises whether disagreement can be equilibrium action if beliefs are compatible. The answer is yes, since the parties can disagree when beliefs are identical, as a consequence of the particular equal distance assumption that was made above (see the example in section 3 below or refer to the appendix). One can however prove that disagreement can *not* be equilibrium action if beliefs are overly pessimistic, i.e. $C^{au} > C^{af}$:

Property 2: Disagreement (i.e. (C_i^u, C_j^f) , where $C_j > C_i$) can *not* be equilibrium action if $C^{au} > C^{af}$ (i.e. agents are excessively pessimistic)

Proof: The proof will go through all possible cases in which disagreement equilibria can occur. For any pair $(C_i^{u\#}, C_j^{f\#})$, where $C_i^{u\#} < C_j^{f\#}$, to satisfy $C_i^{u\#} \in \{\min C_i \in C: 2C^{au} - C_j^{f\#} < C_i < C_j^{f\#}\}$ and $C_j^{f\#} \in \{\max C_i \in C: 2C^{af} - C_i^{u\#} > C_j > C_i^{u\#}\}$ it must be the case that $C^{af} > C^{au}$, for otherwise either the max or the min problem does not have a solution (that is one of the sets is empty). The

reason is that it cannot be the case that (C_i^{u*}, C_j^{f*}) satisfies both $C^{au} < 1/2(C_j^{f*} + C_i^{u*})$ and $1/2(C_j^{f*} + C_i^{u*}) < C^{af}$ simultaneously unless $C^{af} > C^{au}$. The case in which the pair (C_i^{u*}, C_j^{f*}) satisfies

$$C_i^{u*} \in \{C_i \in C: C_i = 2C^{au} - C_j^{f*}\}$$

$$\text{and } C_j^{f*} \in \{C_j \in C: C_j = 2C^{af} - C_i^{u*}\}$$

can only occur if $C^{af} = C^{au}$. The two remaining cases:

$$C_i^{u*} \in \{\min C_i \in C: 2C^{au} - C_j^{f*} < C_i < C_j^{f*}\}$$

$$\text{and } C_j^{f*} \in \{C_j \in C: C_j = 2C^{af} - C_i^{u*}\}$$

$$\text{or } C_i^{u*} \in \{C_i \in C: C_i = 2C^{au} - C_j^{f*}\}$$

$$\text{and } C_j^{f*} \in \{\max C_j \in C: 2C^{af} - C_i^{u*} > C_j > C_i^{u*}\}$$

also only have solutions if $C^{af} > C^{au}$ (for the same reasons as above). This exhausts the possibilities in which a disagreement equilibria can exist.

This then indicates that in the cases in which beliefs are either identical or incompatible one cannot rule out that equilibrium final offers might imply to both agree and to disagree. However, disagreement, in the case of identical expectations, can be equilibrium action because of the particular equal distance assumption made. It therefore seems sensible to concentrate on the case of incompatible beliefs only. In property 3 I will give a simple set of sufficient (but not necessary) conditions for disagreement to be equilibrium action.

Property 3: A set of sufficient conditions for there to exist equilibrium offers (C_i^{u*}, C_j^{f*}) , where $C_i^{u*} < C_j^{f*}$ (i.e. the firm demands more than the union offers), are

$$C^{af} > \max \left\{ (1/\delta)C^{au}, \delta C^{au} + (1-\delta)\pi \right\}.$$

Proof: I will construct an equilibrium (C_i^{u*}, C_j^{f*}) for which $C_i^{u*} \leq C^{au} < C^{af} \leq C_j^{f*}$. If $C^{af} \leq C_j^{f*}$ then there exists a $C_i^{u*} \in \{\min C_i \in C: 2C^{au} - C_j^{f*} < C_i < C_j^{f*}\}$ for which $C_i^{u*} \leq C^{au}$ since the sufficient condition requires that $C^{au} < C^{af}$. Equally if $C_i^{u*} \leq C^{au}$ then there exists a $C_j^{f*} \in \{\max C_j \in C: 2C^{af} - C_i^{u*} > C_j > C_i^{u*}\}$ for which $C^{af} \leq C_j^{f*}$ since the sufficient condition requires that $C^{au} < C^{af}$. It therefore follows that there exists a (C_i^{u*}, C_j^{f*}) , where

$$C_i^{u*} \in \{\min C_i \in C: 2C^{au} - C_j^{f*} < C_i < C_j^{f*}\}$$

$$\text{and } C_j^{f*} \in \{\max C_j \in C: 2C^{af} - C_i^{u*} > C_j > C_i^{u*}\}$$

for which $C_i^{u*} \leq C^{au} < C^{af} \leq C_j^{f*}$. It remains to be shown that no player has an incentive to deviate, i.e. one now has to show that $\delta(\pi - C_i^{u*}) \geq (\pi - C_j^{f*})$

and that $\delta C_j^{f*} \geq C_i^{u*}$. The first of these conditions is satisfied because $\delta(\pi - C_i^{u*}) \geq \delta(\pi - C^{au}) > (\pi - C^{af}) \geq (\pi - C_j^{f*})$ due to the construction of the equilibrium and the sufficient condition. For the same reason it must be the case that $\delta C_j^{f*} \geq \delta C^{af} > C^{au} \geq C_i^{u*}$. Note that the sufficient condition also rules out the equal distance cases since the strategy space $C = \{C_0, \dots, C_k\} = \{l : l=0, \dots, k\}$ ensures that $\delta(\pi - C_i^{u*}) \geq \delta(\pi - 1/2(C_{i-1}^u + C_j^{f*}))$ and that $\delta C_j^{f*} \geq 1/2(C_i^{u*} + C_{j+1}^f)$ (both follow because $C_j^f \geq C_i^{u*} + 1$), in the cases for which such C_{i-1}^u and C_{j+1}^f exist, that is, as long as $C_{i-1}^u \in C$ $C_{j+1}^f \in C$. This completes the proof.

As can be seen from the above condition $\max\{(1/\delta)C^{au}, \delta C^{au} + (1-\delta)\pi\}$ decreases with δ so that the higher the direct costs of arbitration the smaller the set of disagreement equilibria (at least as far as this sufficient condition is concerned). The opposite condition will of course result in the case of agreement equilibria. In the following property I will give a necessary and sufficient condition for agreement to be equilibrium action (in the case of incompatible beliefs).

Property 4⁹: Assume that $C^{af} > C^{au}$. There exists an agreement equilibrium (C_i^{u*}, C_i^{f*}) if:

$$\min\{\delta\pi; [\delta/(1+\delta)](2C^{af}-1)\} \leq C_i^* \leq \max\{(1-\delta)\pi; [\delta(2C^{au}+1)+(1-\delta)\pi]/(1+\delta)\}$$

Proof: For the firm to prefer C_i , given C_i^{u*} , to any other choice it is required that $C_i^{u*} \geq \delta C_m^f$ if there exists a C_m^f such that $C_i^{u*} < C_m^f \leq 2C^{af} - C_i^{u*} - 1$; otherwise it must be the case that $C_i^{u*} \geq \delta\pi$. It therefore follows that the firm prefers C_i^* to any other action if

$$C_i^* \geq \min\{\delta\pi; [\delta/(1+\delta)](2C^{af}-1)\}.$$

Note that since $C^{af} > C^{au}$ it must be the case that $C_m^u \geq 1/2(C_i^{u*} + C_m^f + 1)$ since $C_m^f \geq C_i^{u*} + 1$ (should such C_m^f and $C_{m+1}^f = C_m^f + 1$ exist) so that the equal distance case does not apply. Equally for the union to prefer C_i , given C_i^{f*} , to any other choice it is required that $(\pi - C_i^{f*}) \geq \delta(\pi - C_n^u)$ if there exists a C_n^u such that $C_i^{f*} > C_n^u \geq 2C^{au} - C_i^{f*} + 1$; otherwise $(\pi - C_i^{f*}) \geq \delta\pi$ (that is and $C_n^u \geq 0$). It follows that the union prefers C_i^* to any other choice if

$$C_i^* \leq \max\{(1-\delta)\pi; [\delta(2C^{au}+1)+(1-\delta)\pi]/(1+\delta)\}.$$

⁹ I would like to thank Jim Mirrlees for lots of help with characterising this solution.

As above if $C^{af} > C^{au}$ it must be the case that $(\pi - C_n^u) \geq (\pi - 1/2(C_n^u - 1 + C_l^{f*}))$ since $C_n^u + 1 \leq C_l^{f*}$ (should such C_n^u and $C_n^u - 1$ exist). This once again implies that the equal distance case is of no importance in determining if something is an agreement equilibrium once it is assumed that $C^{af} > C^{au}$.

As can be seen from the above condition the number of agreement equilibria increases with the direct costs of arbitration. This is of course intuitive and similar to the analysis of indirect costs in the usual final offer arbitration models. Since the direct costs of arbitration are somewhat more tangible (and easier to trace) than the indirect costs due to risk aversion, the analysis of this paper makes a step in the direction of assessing the consequences of compulsory final offer arbitration.

Clearly, whenever the conditions of properties 3 and 4 are satisfied simultaneously then *both* agreement and disagreement may occur in equilibrium. Below I will describe sufficient conditions for two of the four cases in which this can occur. Property 5 describes a situation in which such strategic multiplicity can occur when neither of the parties has very extreme beliefs about the arbitrator. Property 6 will look at the opposite case in which both agents have extreme beliefs about the arbitrator's ideal settlement. The two remaining cases can be analysed in a similar way.

Property 5: Let beliefs be incompatible (i.e. $C^{af} > C^{au}$). Then if

$1/2\pi \geq [C^{af} - 1/2]/(1 + \delta)$
 and $1/2\pi \leq [C^{au} + 1/2]/(1 - \delta)$
 and $1/2\pi > \max\{C^{au}; \delta(\pi - C^{au})\} + 1/(2(1 + \delta))$
 then both agreement and disagreement constitutes equilibrium action simultaneously (i.e. there exist multiply equilibria and some equilibria imply agreement and some imply disagreement)

Proof: Note first of all that if $1/2\pi \geq [C^{af} - 1/2]/(1 + \delta)$ and if $1/2\pi \leq [C^{au} + 1/2]/(1 - \delta)$ then $\delta\pi \geq [\delta/(1 + \delta)](2C^{af} - 1)$ and $(1 - \delta)\pi \leq [\delta(2C^{au} + 1) + (1 - \delta)\pi]/(1 + \delta)$. It therefore follows from property 4 that an agreement equilibrium exists if

$$[\delta/(1 + \delta)](2C^{af} - 1) + 1 \leq [\delta(2C^{au} + 1) + (1 - \delta)\pi]/(1 + \delta)$$

After manipulating this equation one then gets that

$$k \equiv C^{af} - C^{au} \leq (1/2\delta)[(1 - \delta)\pi - 1]$$

Now from property 3 one knows that disagreement equilibria exist if

$$k \equiv C^{af} - C^{au} > \max \{ ((1-\delta)/\delta)C^{au}; \delta(\pi - C^{au}) \}.$$

When combining these two equations and manipulating them a little one gets $1/2\pi > \max\{C^{au}; d(\pi - C^{au})\} + 1/(2(1+\delta))$ which completes the proof.

In order to see that these equations may allow a solution choose for example $\pi=100000$, $\delta=0.9$ and $(C^{af}, C^{au})=(55000, 45000)$ which satisfies them. This example shows that discounting need not be very extreme for there to exist agreement and disagreement equilibria once neither the union nor the firm have very extreme beliefs about the arbitrator. As will be seen in the next property, once the bargaining parties have extreme beliefs about the arbitrator then one requires rather extreme arbitration costs and delays for there to exist both agreement and disagreement equilibria. This is of course intuitive.

Property 6: Let beliefs be incompatible, i.e. $C^{af} > C^{au}$. Then if

$$1/2\pi \leq [C^{af} - 1/2]/(1+\delta)$$

$$\text{and } 1/2\pi \geq [C^{au} + 1/2]/(1-\delta)$$

$$\text{and } \delta \leq (1/2)[1 - 1/\pi]$$

$$\text{and } C^{af} > \max \{ (1/\delta)C^{au}, \delta C^{au} + (1-\delta)\pi \}$$

then both agreement and disagreement constitutes equilibrium action simultaneously (i.e. there exist multiply equilibria and some equilibria imply agreement and some imply disagreement)

Proof: Note first of all that if $1/2\pi \leq [C^{af} - 1/2]/(1+\delta)$ and if

$$1/2\pi \geq [C^{au} + 1/2]/(1-\delta) \text{ then } \delta\pi \leq [\delta/(1+\delta)](2C^{af} - 1) \text{ and}$$

$(1-\delta)\pi \geq [\delta(2C^{au} + 1) + (1-\delta)\pi]/(1+\delta)$. It therefore follows from property 4 that an agreement equilibrium exists if

$$\delta\pi + 1 \leq (1-\delta)\pi, \text{ that is if } \delta \leq (1/2)[1 - 1/\pi]$$

Now from property 3 one knows that disagreement equilibria exist if

$$C^{af} > \max \{ (1/\delta)C^{au}, \delta C^{au} + (1-\delta)\pi \}.$$

which completes the proof.

A simple example of this case is to let $\pi=100$, $\delta=0.4$ and $(C^{af}, C^{au})=(\pi, 0)$ which satisfies all of the required conditions and this for a large range of discount rates. Many other examples can of course also be given.

3. The Contract Zone

A '(positive) contract zone', probably the central concept in the arbitration literature, describes the range of agreements that both parties prefer to final offer arbitration. In the above model the contract zone is described by the set of equilibria which imply agreement. The model of this paper however also characterises the set of equilibria which imply disagreement- that is that the agents proceed to the arbitrator. (A full characterisation of equilibrium is in the appendix). That this set is characterised is a great advantage of this paper since it sheds light on and clarifies a debate of whether a positive contract zone (i.e. a non-empty set of equilibria which imply agreement) is sufficient for agreement to occur (see in particular Bloom [1981] and Bloom and Cavanagh [1987]). This debate also underlies most of the empirical and experimental tests in the arbitration literature. In fact, it is almost always assumed that a positive contract zone implies that the bargaining parties do not invoke an arbitrator solution (See for example Farber and Bazerman [1989] and Babcock and Olsen [1992]).

That agents might not always agree when a contract zone exists was for example argued by Bloom and Cavanagh:

"... the existence of a contract zone is necessary, but not sufficient, for arbitration to lead to a voluntary settlement because there may be substantial direct costs of negotiation as well as uncertainty about settlement points within the contract zone..." (page 354)

Much lip service was paid to this point of view, which was first put forward by Bloom [1981]. However, probably because worries about common knowledge and coordination do not tend to carry much weight in equilibrium analysis, such doubts made little difference to the mode of analysis. This is were the insights of the previous section enter. Even if there exists a positive contract zone (that is even if there exist equilibria which imply agreement) may there exist (pure strategy) equilibria which imply disagreement. This was the content of properties 5 and 6. The statement that "the existence of a contract zone is necessary, but not sufficient, for arbitration to lead to a voluntary settlement" is therefore correct with respect to the model in this paper and is based entirely on equilibrium reasoning which does not require mixing.

The reasons Bloom [1981] and Bloom and Cavanagh [1987] give are not necessary for this to occur in the above model. First, the reference to coordination problems (arising due to mixing or problems of common knowledge) is not at all necessary since properties 5 and 6 proved that there may be equilibria which imply disagreement even if there exist equilibria which imply agreement. Calling in an arbitrator is therefore independent of whether a contract zone exists, i.e. whether there exist equilibria which imply agreement. Second, substantial costs of negotiation do not enter in the above analysis and should have no effect on the final offers. Substantial costs of arbitration do however enter and partially define the set of equilibria, including the contract zone. Yet, even if there exist substantial costs to disagreement may there exist equilibria which imply disagreement (and this even if beliefs are identical). This can be seen in the following example:

Let $C=\{0;1;2\}$ and $(C^{au},C^{af})=(1;1)$, that is, the union and the firm have identical beliefs. Expected payoffs are then as in the figure 1 below.

| | | F | | |
|----------|---|----------------|----------------|----------------|
| | | 0 | 1 | 2 |
| U | 0 | (2 ; 0) | δ (1;1) | δ (1;1) |
| | 1 | (1.5; ;0.5) | (1 ; 1) | δ (1;1) |
| | 2 | (1 ; 1) | (0.5; ;1.5) | (0 ; 2) |

Figure 1

As can be see from inspecting the payoffs in figure 1 both (1;1) and (0;2) are pure strategy equilibria. Hence, even though beliefs about the arbitrator's true preferences are identical, calling in an arbitrator constitutes equilibrium action, and this even for substantial direct costs of disagreement. That this can occur is not particular to the example chosen; however in games with bigger strategy spaces these situations can generally not arise for all δ s.

With respect to this model it is therefore not enough to calibrate a contract zone and then to check whether agents ended up agreeing. In this model such an approach may only be valid if agents have overly pessimistic

expectations (leaving aside Bloom's point about coordination problems). The validity of this testing approach then boils down to whether agents are expected to have overly pessimistic expectations. However as will be explained in the next section, the answer to this question has often been mixed up in debates on the size and existence of a contract zone.

4. Reevaluating the Divergent Expectations Hypothesis

The results of this model have their greatest impact on Farber's model and the testing methodology that followed it if expectations about the arbitrator are either identical or overly optimistic. The question of whether and to what extent agents have divergent expectations is therefore of some importance. Arguments for and against the divergent expectations hypothesis have been supplied on two very different levels. On the one side the debate was carried out on a more or less empirical/experimental level; on the other side arguments of a more 'theoretical' nature were employed. Let me discuss the empirical/ experimental evidence first.

4.1. Empirical Evidence

There exists little direct evidence on the divergent expectations hypothesis. Bazerman and Neale [1982] asked subjects in a bargaining experiment with what probability they expect that their final offer will be accepted. The average probability estimate was 68%. This is therefore evidence in favour of the divergent expectations hypothesis and thus, within the context of the model of this paper, might mean that there may be multiple equilibria some of which imply agreement and some of which imply an arbitrated solution. Bazerman and Neale [1982] and Babcock and Olson [1992] also cite other, less relevant or direct, experimental evidence from the psychology literature which could also be interpreted as implying support for the divergent expectations hypothesis.

Babcock and Olson [1992] use a proxy to derive the parties' beliefs about arbitration and then use the equilibrium conditions to derive the contract zone. They then claim that the divergent expectations hypothesis requires evidence that settlements were negotiated when a positive contract zone existed and that disputes were settled by final offer arbitration when a 'negative'

contract zone existed. A result they then derive is that 86% of the parties who received final offer awards had an estimated positive contract zone (and that only 14% of the parties who received final offer awards had negative contract zones). Naturally they therefore reject the divergent expectation hypothesis. Their concern that "this indicates that even when the parties could conceivably settle voluntarily, they often choose to receive a final offer award" (page 356) points directly to the model of this paper. The finding that 86% of the parties who received final offer awards had an estimated positive contract zone (and should therefore, according to the standard theory, have negotiated a settlement without referring to an arbitrator) can be interpreted as evidence for the model of this paper since the existence of a contract zone need not imply that disagreement can not also be equilibrium action. Furthermore, this ambiguity in equilibria can only arise in my model if expectations about the arbitrator are on the whole divergent and if there are furthermore costs to disagreement. It would therefore appear that the parties who go to final offer arbitration on the whole have divergent expectations. Hence, when interpreting the evidence of Babcock and Olsen in the context of the model of this paper their results start to make sense and their conclusion that the evidence is unfavourable to the divergent expatiations hypothesis is furthermore turned on its head. This is rather intriguing.

Farber and Bazerman [1989] test for the 'sufficiency' of divergent expectations (after arguing that they are 'necessary') by comparing identical expectation contract zones¹⁰ under final offer arbitration and under conventional arbitration. They argue that identical expectations contract zones "will be larger under the form of arbitration that leads to the higher settlement rate" (page 101). The reason they give is that larger identical expectations contract zones will be more likely to lead to agreement in actual cases where expectations may well differ (because in these cases contract zones would otherwise not exist). The authors therefore claim that if final offer arbitration leads to fewer disagreements than conventional arbitration it should also imply larger identical expectations contract zones. The authors cite evidence that final offer arbitration leads to more settlements than conventional arbitration. Since the authors find however that identical

¹⁰ A contract zone is the range of agreements that both parties prefer to disagreement. The identical expectations contract zone is the contract zone calculated under the hypothesis of identical expectations (see Farber and Bazerman [1989]).

expectations contract zones are larger under conventional arbitration than under final offer arbitration they have to reject the hypothesis that divergent beliefs are 'sufficient' to explain disagreement. (As a matter of fact, on these grounds they also reject an asymmetric information hypothesis). Ashenfelter et al. [1992] find, however, that the dispute rate in a final offer arbitration system is at least as high as the dispute rate in a comparable conventional arbitration system; this would imply that the 'sufficiency hypothesis' might actually go through.

The test of Farber and Bazerman can be criticised on several grounds. First, it presumes that divergent beliefs have the same effect under both conventional and final offer arbitration. Since the authors have no equilibrium theory of divergent beliefs this assumption is ad hoc. Second, it presumes that larger contract zones lead to less disagreement. This hypothesis is for example contested in Bloom [1981] and Bloom and Cavanagh [1987]. It also implies that a positive contract zone leads to agreement, a conclusion that can not be drawn in the context of my model.

To summarise, the scarce empirical and experimental evidence that exists although partially contradictory is on the whole favourable to the divergent expectations hypothesis and to the relevance of the model of this paper. However more experimental and empirical evidence is clearly required.

4.2. Arguments of a more theoretical nature

Evidence which could be interpreted as being unfavourable to the divergent expectations explanation comes from the 'arbitrator exchangeability' hypothesis. This hypothesis, which has been confirmed in several studies, states that arbitrators operate within a process that makes them statistically exchangeable (see for example Ashenfelter et al [1992], Ashenfelter [1987], Bloom and Cavanagh [1987] and Farber and Bazerman [1986]). In Ashenfelter et al [1992] this hypothesis for example takes the following form:

"... exchangeability requires that there be no predictable differences. ... Statistical exchangeability of arbitrators implies that the arbitrator decision may be modelled as being based on random draws from a fixed distribution,..." (page 1048)

The fixed distribution is of course taken to be the same for both agents. From this one could conclude that negotiators ought not hold divergent expectations

about the arbitrator's settlement, i.e. they should hold mean expectations from some objective distribution. Such a conclusion can be contested on several grounds. Arbitrators have to be approved by both parties (see Bloom and Cavanagh [1986] and [1987] for a review of arbitrator selection mechanisms). It is therefore likely that an arbitrator is chosen from which both agents expect to receive a favourable outcome. One of the agents must in this case end up disappointed; however, this is inevitable and the direct consequence of selecting an arbitrator.

Arbitrators earn fees from arbitration (like lawyers). It therefore is in their interest to be called to settle a dispute, and thus to create expectations which please both¹¹. Divergent expectations do allow the arbitrator to be 'statistically exchangeable' since the arbitrator can ex post still act in a statistically exchangeable way. The reason is that the underlying preferences of the arbitrator and the beliefs about them are not observable. Nurturing divergent expectations does therefore not need to damage the reputation of an arbitrator as long as he or she fosters divergent expectations in not too obvious a way. Arbitrators for which this becomes too obvious are substituted. Hence once agents 'learn' that their expectations were wrong (it can take a long time for this to occur) then a new arbitrator enters who starts the game anew.

A second class of arguments made against the divergent expectations hypothesis concerns the human capability to learn¹². Such learning arguments were generally made in a rather informal way. Farber and Katz [1979] for example dismiss divergent expectations as a satisfactory explanation since they consider that:

" It is reasonable to believe that over time the parties learn about the arbitrator's behaviour both through their own experience and, indirectly, through the experience of others" (page 59)

¹¹Such a view is not incompatible with the standard one advanced by Farber and Bazerman [1986]: "...one possible motivation for arbitrators is that they attempt to make awards that maximise the probability they will be hired in subsequent cases, either by the same parties or by others who are aware of their performance." (page 1506).

¹² I do not here refer to models like that of Gibbons [1988] where agents update their knowledge about some underlying and relevant piece of information via some signal or action.

From this they then conclude that 'learning' will imply that the means and variances of the negotiators' prior distributions will converge over time. This might or might not be the case depending on how one models 'learning'. There have however also been slightly more formal arguments which invoke 'agreeing to disagree' type results (see Aumann [1976] and Fudenberg and Tirole [1991]). Crawford [1985] and Bloom and Cavanagh [1987] interpreted Farber [1980] as stating that divergent beliefs are to be modelled via common priors and private information. Crawford then claimed that to model divergent beliefs via common priors and private information does not work since 'no trade theorems'¹³ as in Milgrom and Stockey [1982] apply¹⁴. However, such appeals to 'agree to disagree' results, even if they could be shown to be correct and relevant, neither apply to the model of Olson and Babcock [1992] nor do they apply to mine since in both models agents have divergent priors..

Finally, there is the view that, ultimately, what are believed to be differences in beliefs are differences in private information. (Kennan and Wilson's [1993] attack on the divergent expectations hypothesis is a case in point¹⁵.) Debating such a view is not different than to argue about what came

¹³ No trade theorems are closely related to 'agreeing to disagree' results as in Aumann [1976]- see Fudenberg and Tirole [1991]

¹⁴ There is however some evidence that Crawford was confused about this issue (or at least he expressed his ideas very badly), for in Crawford [1982, page 72] he states that "... the bargainers' priors about the arbitrators preferences are common knowledge (and therefore identical by Aumann's (1976) result)..." Of course Aumann's result says nothing of the sort. Aumann's result requires that the players' beliefs be derived by Bayesian updating from the common prior distribution he assumes. Then, once the information partitioning and the posteriors are common knowledge, then posteriors have to be identical. (See Aumann's article or Fudenberg and Tirole [1991]). Also Bloom and Cavanagh [1987, page 354] seem to follow such a line since they state that "... bargainers will tend to reconcile their prior expectations about an arbitrator's behaviour in the negotiations leading up to the arbitration (see for example Geanakoplos and Polemarchakis [1982])". The article of Geanakoplos and Polemarchakis proves an Aumann type result, however, which requires common priors.

¹⁵ "We favour the third criticism, however, which is that divergent expectations are predicted and explained by private information- and found to be inconsequential..." (Kennan and Wilson [1993], page 91).

first, the chicken or the egg? In the end such arguments just describe modelling preferences¹⁶.

5. Conclusions

This paper presented a model of final offer arbitration slightly different (and possibly slightly more realistic) to the standard Farber [1980] model. The small difference in modelling did however yield important advantages and new insights. First it allowed one to consider the consequences of the direct costs of arbitration on the final offers, something that has been neglected in the literature. Second, the model of this paper fully characterised the set of equilibrium offers and described a class of cases for which the set of equilibria can consist of both (pure strategy) agreement and (pure strategy) disagreement equilibria. This showed that the concepts of a 'positive' and 'negative' contract zones are not mutually exclusive, as was generally presumed in the literature. These new insights are then used in order to reconsider a debate of whether the existence of a positive contract zone is sufficient for agents to agree.

Since the model is driven by divergent beliefs the question of when and whether agents have divergent beliefs is of some importance. This paper used the opportunity to partially reevaluate the debate (and the evidence supporting it) in the light of the model of this paper. My conclusion was that the experimental and empirical evidence on the topic, although still scarce, is on the whole rather favourable to the divergent beliefs hypothesis. The theoretical arguments on the topic are on the whole unconvincing. This then suggests that the theory in this paper might be useful in understanding arbitration.

Appendix

This appendix fully characterises the set of equilibria. Remember that C_i^u is U's final offer of what F gets and C_i^f denotes what F asks for itself. A way of describing the offers of interest, leaving the diagonal pairs $C_i^u=C_i^f$ aside for a

¹⁶ For a more thorough discussion of the common prior assumption see Morris [1993].

moment, is by way of the following sets (which were already used in several proofs in section 2.2):

$$\begin{aligned} C_{\min}(C_{au}, C_{jf}^*) &= \{\min C_i \in C: 2C_{au} - C_{jf}^* < C_i < C_{jf}^*\} \\ C_{\max}(C_{af}, C_{iu}^*) &= \{\max C_i \in C: 2C_{af} - C_{iu}^* > C_i > C_{iu}^*\} \\ C_{eq}(C_{au}, C_{jf}^*) &= \{C_i \in C: C_i = 2C_{au} - C_{jf}^*\} \\ C_{eq}(C_{af}, C_{iu}^*) &= \{C_i \in C: C_i = 2C_{af} - C_{iu}^*\} \end{aligned}$$

These sets are either empty or contain one element- the offer of interest. It can be seen that the sets $C_{\min}(C_{au}, C_{jf}^*)$ and $C_{\max}(C_{af}, C_{iu}^*)$ would always be empty if the strategy space were continuous. This problem would remain if, for example, the arbitrator had a rule which gave everything to U and nothing to F in the case in which U and F made offers equally far away from C_a .

The set of matching final offers (C_{iu}^*, C_{jf}^*) define equilibrium offers unless:

$$\begin{aligned} &C_{\min}(C_{au}, C_{jf}^*) \neq \emptyset \text{ and } \delta(\pi - C_{pu}) > (\pi - C_{iu}^*) \text{ where } C_{pu} \in C_{\min}(C_{au}, C_{jf}^*) \\ \text{or } &C_{eq}(C_{au}, C_{jf}^*) \neq \emptyset \text{ and } \delta(\pi - 1/2(C_{pu} + C_{jf}^*)) > (\pi - C_{iu}^*) \text{ where } C_{pu} \in C_{eq}(C_{au}, C_{jf}^*) \\ &\text{and unless} \\ &C_{\max}(C_{af}, C_{iu}^*) \neq \emptyset \text{ and } \delta C_{pf} > C_{jf}^* \text{ where } C_{pf} \in C_{\max}(C_{af}, C_{iu}^*) \\ \text{or } &C_{eq}(C_{af}, C_{iu}^*) \neq \emptyset \text{ and } \delta 1/2(C_{pf} + C_{iu}^*) > C_{jf}^* \text{ where } C_{pf} \in C_{eq}(C_{af}, C_{iu}^*) \end{aligned}$$

where $C_{\min}(C_{au}, C_{jf}^*)$, $C_{\max}(C_{af}, C_{iu}^*)$, $C_{eq}(C_{au}, C_{jf}^*)$ and $C_{eq}(C_{af}, C_{iu}^*)$ were defined above. Note that there might not exist C_{pu} and C_{pf} which satisfy the maximising, minimising and equality problems which constrain the deviations from equilibrium. In these cases (C_{iu}^*, C_{jf}^*) is an equilibrium since all other deviations lead to lower expected payoffs. The reason why always two conditions for each player are required is that the equal distance case in the arbitration rule introduces an extra possibility which has to be considered (which however becomes irrelevant once beliefs are incompatible- see the arguments in the proofs of properties 3 and 4). For this reason it is also slightly more cumbersome to define the set of equilibrium offers which imply disagreement.

For any pair (C_{iu}^*, C_{jf}^*) , where $C_{iu}^* < C_{jf}^*$, to satisfy $C_{iu}^* \in C_{\min}(C_{au}, C_{jf}^*)$ and $C_{jf}^* \in C_{\max}(C_{af}, C_{iu}^*)$ it must be the case that $C_{af} > C_{au}$ for otherwise it cannot be the case that $C_{au} < 1/2(C_{jf}^* + C_{iu}^*) < C_{af}$. The same requirement is necessary

for (C_i^{u*}, C_j^{f*}) , where $C_i^{u*} < C_j^{f*}$, to satisfy $[C_i^{u*} \in C_{\min}(C_{au}, C_i^{f*})$ and $C_j^{f*} \in C_{\text{eq}}(C_{af}, C_i^{u*})]$ and $[C_j^{f*} \in C_{\max}(C_{af}, C_i^{u*})$ and $C_i^{u*} \in C_{\text{eq}}(C_{au}, C_j^{f*})]$. On the other hand for any such pair to satisfy $C_i^{u*} \in C_{\text{eq}}(C_{au}, C_i^{f*})$ and $C_j^{f*} \in C_{\text{eq}}(C_{af}, C_i^{u*})$ it must be the case that $C_{af} = C_{au}$ for otherwise it cannot be the case that $C_{au} = 1/2(C_j^{f*} + C_i^{u*}) = C_{af}$. Remember that the strategy space was assumed to be $C = \{C_0, \dots, C_k\} = \{l: l=0, 1, 2, \dots, k\}$ which implies that if $C_i^{u*} = C_{j-1}^{f*}$ then $1/2(C_j^{f*} + C_{i-2}^{u*}) = C_{j-1}^{u*}$. For $C_i^{u*} = C_{j-1}^{f*}$ where $l > 2$ it follows that $1/2(C_j^{f*} + C_{i-1}^{u*}) < C_{j-1}^{u*}$. This implies that an element of $C_{\min}(C_{au}, C_i^{f*})$ (or $C_{\max}(C_{af}, C_i^{u*})$), should one exist, can never yield a lower payoff than an element of $C_{\text{eq}}(C_{au}, C_i^{f*})$ and (or $C_{\text{eq}}(C_{af}, C_i^{u*})$), should one exist. The pair (C_i^{u*}, C_j^{f*}) , where $C_i^{u*} < C_j^{f*}$, are equilibrium offers if

$C_{af} > C_{au}$

and if $\delta(\pi - C_i^{u*}) \geq (\pi - C_j^{f*})$ where $C_i^{u*} \in C_{\min}(C_{au}, C_j^{f*})$

and if $\delta C_j^{f*} \geq C_i^{u*}$ where $C_j^{f*} \in C_{\max}(C_{af}, C_i^{u*})$

or if

$\delta(\pi - C_i^{u*}) \geq (\pi - C_j^{f*})$ where $C_i^{u*} \in C_{\min}(C_{au}, C_j^{f*})$

and if $C_{\text{eq}}(C_{af}, C_i^{u*}) \neq \emptyset$ then $\delta 1/2(C_j^{f*} + C_i^{u*}) \geq C_i^{u*}$

and if $\delta 1/2(C_j^{f*} + C_i^{u*}) \geq \delta(\pi - C_{j-1}^{f*})$ where $C_j^{f*} \in C_{\text{eq}}(C_{af}, C_i^{u*})$

or if

$C_{\text{eq}}(C_{au}, C_i^{f*}) \neq \emptyset$ and $\delta(\pi - 1/2(C_i^{u*} + C_j^{f*})) \geq (\pi - C_j^{f*})$

and if $\delta(\pi - 1/2(C_i^{u*} + C_j^{f*})) \geq \delta C_{i+1}^{u*}$ where $C_i^{u*} \in C_{\text{eq}}(C_{au}, C_i^{f*})$

and if $\delta C_j^{f*} \geq C_i^{u*}$ where $C_j^{f*} \in C_{\max}(C_{af}, C_i^{u*})$

or if $C_{af} = C_{au}$

and if $\delta(\pi - 1/2(C_i^{u*} + C_j^{f*})) \geq (\pi - C_j^{f*})$ where $C_i^{u*} \in C_{\text{eq}}(C_{au}, C_j^{f*})$

and if $\delta 1/2(C_j^{f*} + C_i^{u*}) \geq C_i^{u*}$ where $C_j^{f*} \in C_{\text{eq}}(C_{af}, C_i^{u*})$

where $C_{\min}(C_{au}, C_j^{f*})$, $C_{\max}(C_{af}, C_i^{u*})$, $C_{\text{eq}}(C_{au}, C_j^{f*})$ and $C_{\text{eq}}(C_{af}, C_i^{u*})$ were defined above.

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